

NHDOT SPR2 PROGRAM

RESEARCH PROGRESS REPORT

INSTRUCTIONS:

Project Managers and/or research project investigators should complete a progress report at least every three months during the project duration. Reports are due the 5th of the month following the end of the quarter. Please provide a project update even if no work was done during this reporting period.

Project # 26962G		Report Period Year: 2019 <input checked="" type="checkbox"/> Q1 (Jan-Mar) <input type="checkbox"/> Q2 (Apr-Jun) <input type="checkbox"/> Q3 (Jul-Sep) <input type="checkbox"/> Q4 (Oct-Dec)
Project Title: The Living Bridge: A Benchmark for Bridge Monitoring The Living Bridge: Tidal Turbine Deployment System		
Project Investigator: Erin S. Bell Project Co-Investigators: Martin Wosnik, Kenneth Baldwin Phone: (603)862-3850 E-mail: erin.bell@unh.edu		
Research Start Date: sample July 1, 2016	Research End Date: May 30, 2019	Project schedule status: <input type="checkbox"/> X On schedule <input type="checkbox"/> Ahead of schedule <input type="checkbox"/> Behind schedule

Brief Project Description:

This project is a collaborative project between the civil and environmental engineering, mechanical and ocean engineering programs at UNH, the NHDOT and several industrial partners to install of an array of structural health monitoring, environmental and estuarine sensors on the Memorial Bridge in Portsmouth, New Hampshire that will be powered by a tidal turbine attached to one of the bridge piers. The funding for the Tidal Turbine Deployment System is leveraged with funding provided by the National Science Foundation's Partnerships for Innovation (PFI) Program, The Living Bridge: The Future of Smart, Sustainable User-Centered Transportation Infrastructure, and funding provided by the US Department of Energy (DOE) to the UNH Center for Ocean Renewable Energy.

Progress this Quarter (include meetings, installations, equipment purchases, significant progress, etc.):

Benchmark for Bridge Monitoring:

The final instrumentation plan for the structural health monitoring was discussed at the June 28th 2016 technical advisory group meeting in Concord, NH, and was approved on July 18 2016. The structural sensors were installed on the bridge structure in March 2017. The installation was complete on March 8 2017. The sensors are operational. The marine sensors are installed on the turbine support platform and the collected data is integrated with the structural information, mechanical performance information and environmental information. The structural sensors on the vertical guide posts were installed in late October 2017. These sensors are temporary collecting data followed by the installation of the tidal turbine in June 2018. The sensors will be permanently installed to the database when the droop cable is installed to the main connector.

Structural response data from the bridge is continuously collected with high-speed (100Hz) data being collected during lift operational only. A trigger protocol was installed in spring 2018 for this high-speed data collection.

Multi-Scale Structural Model

Based on the validation of the multi-scale structural mode, as shown in Figure 1, additional effort was focused on the multi-scale for lift modeling and damage simulation. PHD candidate Maryam Mashayekhizadeh developed a modeling protocol to simulated the structural experience of the bridge during a lift operation, see Figure 2. This protocol has predicted structural response that is similar is shape and magnitude to the collected structural response of the bridge, as shown in Figure 3.

NHDOT SPR2 PROGRAM RESEARCH PROGRESS REPORT

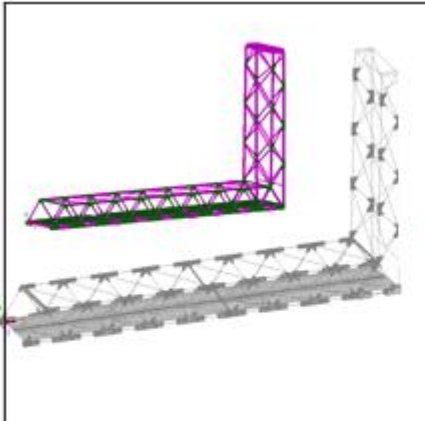
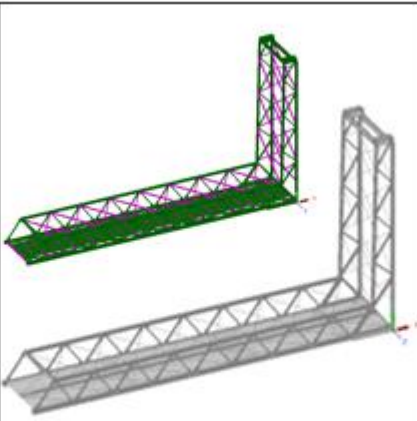
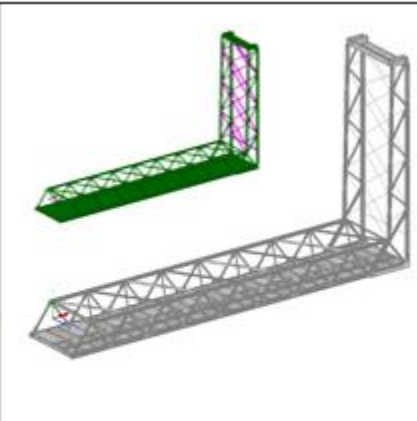
		
Multi-scale model Beam and shell element Structural analysis (Multi-2)	Multi-scale model Beam and shell element Modeling the lift (Multi-1)	Shell element model Shell element (minimal beam elements) Baseline model (shell model)

Figure 1 Multi-Scale Finite Element Model of the Memorial Bridge, Portsmouth, NH

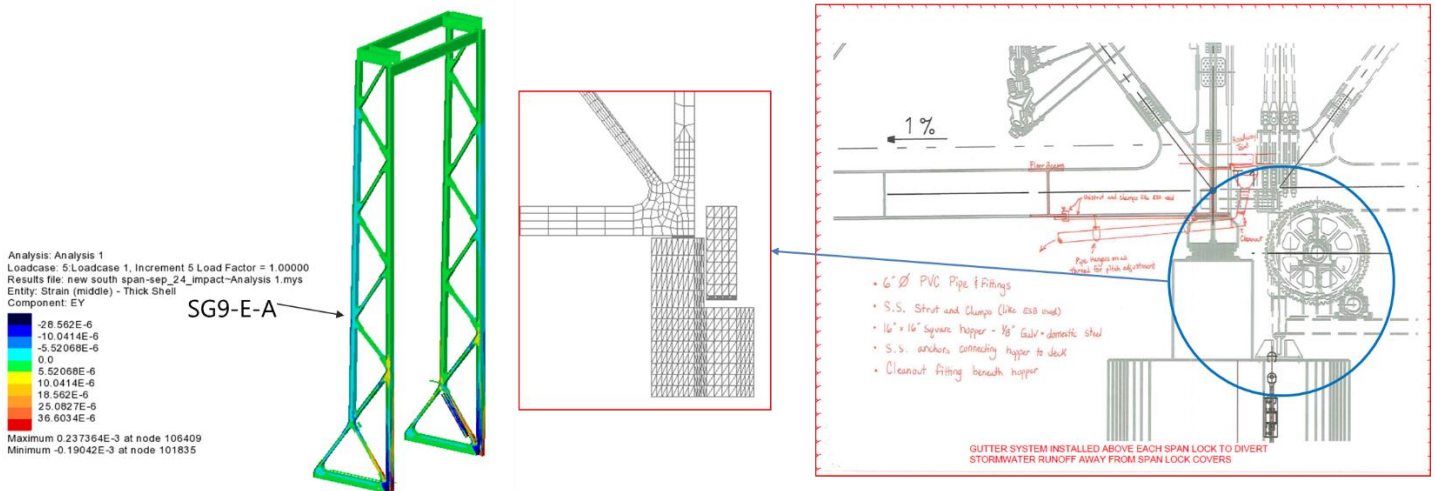


Figure 2 Structural Modeling Protocol Illustration of Lift Loading at the Memorial Bridge

NHDOT SPR2 PROGRAM

RESEARCH PROGRESS REPORT

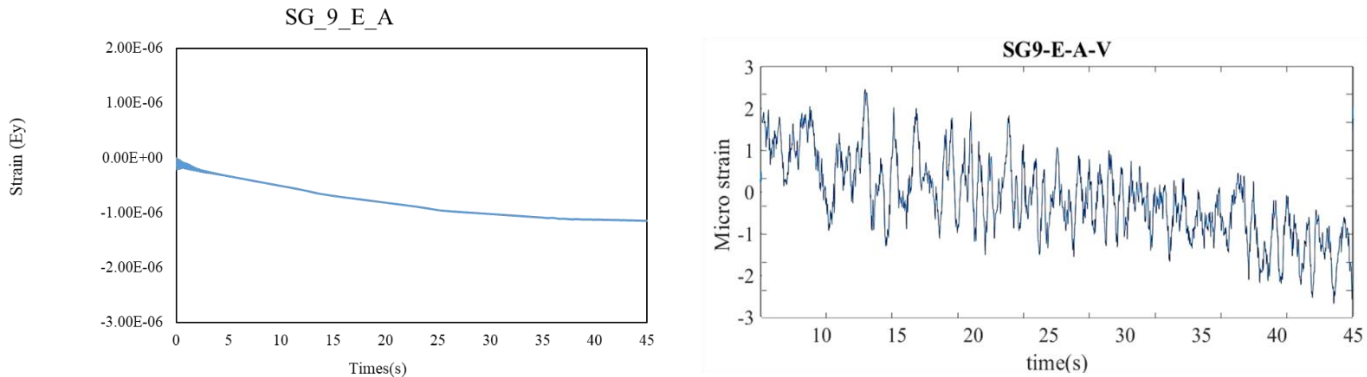


Figure 3 Verification of the (a) Structural Multi-Scale Model as compared to Field Collected data and (b) collected during a Lift Operation at the Memorial Bridge

A senior capstone project for the 2018-2019 academic year is continuing this work using data collected from the vertical guide posts.

PI Bell continues to communicate with bridge designer, Ted Zoli, both in live and virtual meetings. The last conference call was held in September 2018 with Professor Ricardo Medina to discuss this project and program 26962M. The most recent live meeting was a live meeting in New York on November 20th 2018. We are planning a conference call in May 2019 to discuss this project and project 26962M.

Progress of Fatigue Damage Assessment of the critical components at the Memorial Bridge

Doctoral candidate, Maryam Mashayekhzadeh, has performed fatigue damage simulations using the validated multi-scale structural model of the Memorial Bridge. Figure 4 shows three damage scenarios that were simulated in the multiple scale. Using the lift operation load protocol shown in Figure 2, the structural response as SG9 was investigated to determine variation in the response when the structure is damaged. This comparison, shown in Figure 5 shows that SG9 is sensitive to structural damage, even at the fatigue crack. This will continue to be studied and documented through the completion of this project.

The fatigue damage response at the bridges measured through the field collected data has a variable property due to the variable amplitude of the traffic load and environmental excitations. Figure 5 shows the variability in fatigue damage index over a six months data collection period. Acquiring variable fatigue damage responses from the multiple periods varying in time interval and duration, can make the method less reliable. Also, the application of the long periods of data collection for fatigue damage assessment, makes the method less-attractive for the short-term decision making programs on the fatigue life of the bridges. A framework is under development for data collection for repeatable and reliable fatigue performance assessment. The framework will be completed by the end of this project.

NHDOT SPR2 PROGRAM RESEARCH PROGRESS REPORT

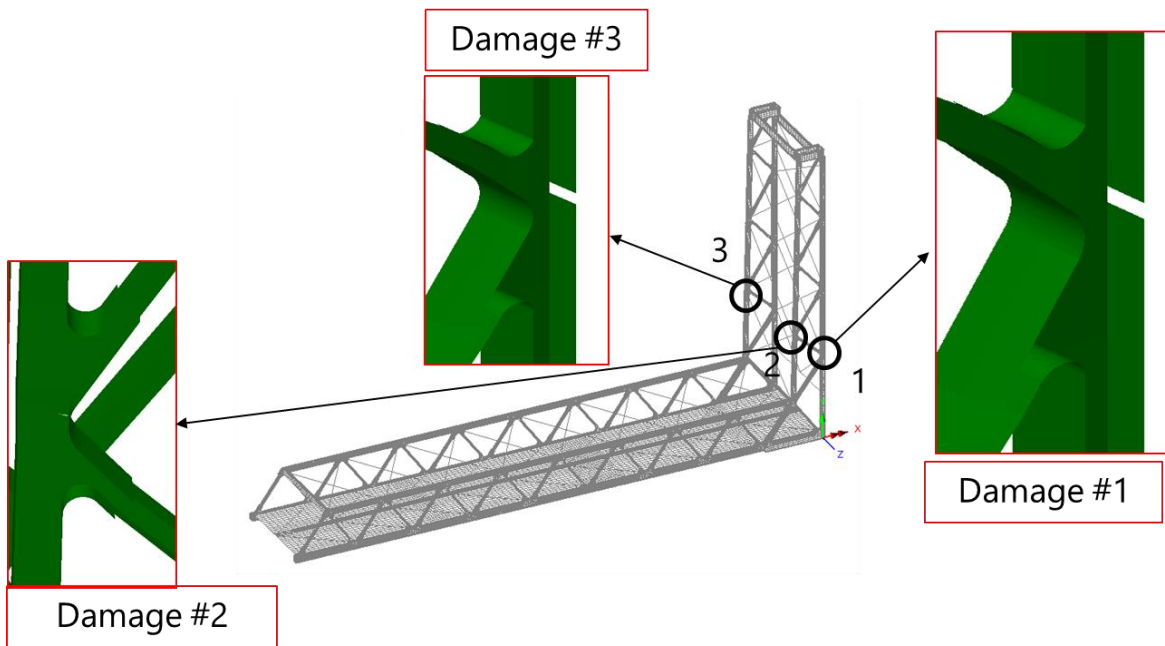


Figure 4 Three Damage Scenarios used to Simulated Lift Operation Response of the Multi-Scale Modeling of the Memorial Bridge

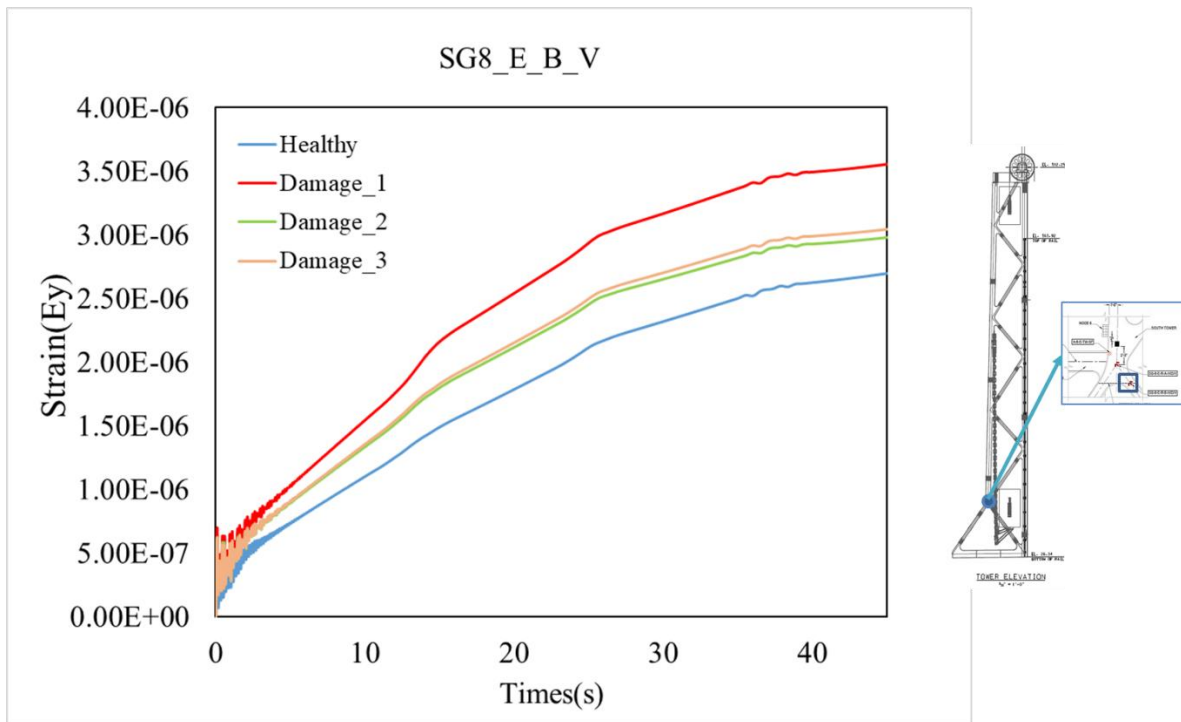


Figure 5 Predicted Structural Response of SG9 during a typical Lift Operation under healthy and damaged condition of the Multi-Scale Modeling of the Memorial Bridge

Progress of model updating, parameter estimation and condition assessment of the Memorial Bridge;

PhD candidate, Milad Mehrkash, developed an API MATLAB-based code to estimate the stiffness parameters of structures. At this step, this code can be used for updating the small-scale and mid-size structures. However, it is in progress to be able to update stiffness parameters of the gusset-less connection of the Memorial Bridge at the end of the project. Also, the potential structural damage to the gusset-less connection of the Memorial Bridge was simulated in ABAQUS® model of the connection and LUSAS® model of the bridge, and the capability and robustness of the SAP2000® model updating procedure for the damage detection, localization and identification will be verified. Milad attended TRB 2018 Conference in Washington,

NHDOT SPR2 PROGRAM

RESEARCH PROGRESS REPORT

D. C., January 2018 to present a literature review about modeling of complicated connections in structural and mechanical systems and propose a methodology for simplified modeling of the Memorial Bridge gussetless connections. Milad and Vahid developed a modal system identification program in MATLAB for extraction of the Memorial Bridge modal parameters from the monitoring data. In May 2018, Milad presented the results of this study in the Engineering Mechanics Institute (EMI) conference in Cambridge, MA. Milad's paper about local model updating of the Memorial Bridge gussetless connection was presented at the SMT & NDT-CE 2018 conference in New Brunswick, NJ in September 2018. He will also present this work at the ASNT conference in California on April 2019

Selected List of peer-reviewed publications:

1. Mashayekhi, M. and Santini-Bell, E. (2018) "Developing three-dimensional multi-scale finite element model for in-plane service performance assessment of bridges" Computer-Aided Civil and Infrastructure Engineering, Published online 11/22/2018. <https://doi.org/10.1111/mice.12424>

Selected List of submissions and presentations:

- Mashayekhizadeh, M., Santini-Bell, E. (2019) "Fatigue assessment of the gusset-less connection in a vertical lift steel bridge using field collected data and three-dimensional multi-scale finite element model" 10th New York City Bridge Conference, New York, August 27-28
- Mashayekhizadeh, M., Santini-Bell, E. (2019) "Detection of damage-induced fatigue response based on structural health monitoring data of in-service steel bridges using Artificial Neural Network" 12th International Workshop on Structural Health Monitoring, IWSHM 2019, Stanford, Ca, September 10-12 (Accepted for presentation).
- Mashayekhizadeh, M., Mehrkash, M., Shahsavari, V. and Santini-Bell, E. (2018) "Multi-scale Finite Element Model Development for Long-Term Condition Assessment of Vertical Lift Bridge", Structures Congress, ASCE, Fort Worth, TX, April 19-21 <https://doi.org/10.1061/9780784481332.008>, (Presented by Mashayekhizadeh, M.)
- Mehrkash, M., Shahsavari, V. and Santini-Bell, E., Instrumentation plan verification for damage detection of a vertical lift steel truss bridge, SPIE Smart Structures and Nondestructive Evaluation, 3-7 March 2019, Denver, CO.
- Milad Mehrkash and Erin Santini-Bell, Local Condition Assessment and Damage Detection of Gusset-less connections Used in a Vertical Lift Truss Bridge, 9th International Conference on Structural Health Monitoring of Intelligent Infrastructure, St. Louis, MO, 2019 (full paper is under review).
- Milad Mehrkash and Erin Santini-Bell, System Identification of a Bridge Gusset-less Connection by Simplified and Detailed Local Analytical Models, NDE/NDT for Highway and Bridges: Structural Materials Technology (SMT 2018) and the International Symposium Non-Destructive Testing in Civil Engineering (NDT-CE 2018), New Brunswick, NJ, 2018.
- Milad Mehrkash, Vahid Shahsavari and Erin Santini-Bell, Instrumentation Sufficiency of a Vertical Lift Bridge for Modal System Identification by Frequency Domain Analysis, Engineering Mechanics Institute Conference, Cambridge, MA, 2018
- Maryam Mashayekhizadeh, Erin Bell "Data Validated Multi-Scale Finite Element Modeling Protocol for Complex Connections of a Movable Bridge", Engineering Mechanics Institute Conference, Cambridge, MA, 2018
- Timothy Nash, Erin Santini-Bell, Milad Mehrkash and Vahid Shahsavari, "An Objective Decision Making Protocol for Lift Bridge Operation Subjected to High Wind Loads", Engineering Mechanics Institute Conference, Boston, MA, 2018.
- Chao Yang, Erin Santini-Bell, Vahid Shahsavari and Milad Mehrkash, "Probability-Based Demand Evaluation of the Bridge Tidal Turbine Deployment System Subject to Environmental Events", Engineering Mechanics Institute Conference, Boston, MA, 2018.
- Maryam Mashayekhizadeh, Milad Mehrkash, Vahid Shahsavari, and Erin Bell, "Multi-Scale Finite Element Model Development for Condition Assessment of Vertical Lift Bridge", ASCE Structures Congress 2018, Fort Worth, TX, April 19-21, 2018.
- Milad Mehrkash and Erin Santini-Bell, "Modeling and Characterization of Complicated Connections in Structural and Mechanical Systems as Applied to a Gusset-less truss connection", 97th Annual Meeting of Transportation Research Board (TRB), Washington D.C, 2018.

NHDOT SPR2 PROGRAM

RESEARCH PROGRESS REPORT

- Maryam Mashayekhizdeh and Erin Santini-Bell, “Influence of temperature on vibration-based structural health monitoring of a vertical bridge”, 27th ASNT Research Symposium, Orlando, FL, 2018.
- Vahid Shahsavari, Milad Mehrkash and Erin Santini-Bell, “Structural Health Monitoring of a Vertical Lift Bridge Using Vibration Data”, 27th ASNT Research Symposium, Orlando, FL, 2018.
- Vahid Shahsavari, “Long-Term Monitoring of Bridges under Operational and Environmental Variations”, The Transportation Research Board (TRB) 97th Annual Meeting, Washington, D.C., January 7-11, 2018.
- Vahid Shahsavari, Milad Mehrkash, Erin Santini-Bell, “Effect of Damaged Structural Members on Performance Degradation of a Vertical Lift Truss Bridge,” ASNT Annual Conference, Houston, TX, October 28-31, 2018.
- Milad Mehrkash, Vahid Shahsavari and Erin Santini-Bell, Instrumentation plan verification for damage detection of a vertical lift steel truss bridge, to be presented at SPIE Smart Structures and Nondestructive Evaluation, Denver, CO, March 3-7, 2019.
- Milad Mehrkash and Erin Santini-Bell, Finite element model updating of the UCF Grid benchmark connections using experimental modal data, to be presented at 37th International Modal Analysis Conference (IMAC-37), January 28-31, 2019, Orlando, FL.
- Milad Mehrkash and Erin Santini-Bell, Investigation of mode shape expansion and reduction techniques for model updating of a steel grid using experimental incomplete modal data, 2019 SEM Annual Conference, Reno, NV, June 3-6, 2019 (abstract is under review).
- Milad Mehrkash, Vahid Shahsavari and Erin Santini-Bell, Monte Carlo sensitivity analysis for local finite element model updating of a gusset-less steel truss bridge, ASNT Research Symposium, Garden Grove, CA, April 1-4, 2019 (abstract is under review).
- Vahid Shahsavari, Milad Mehrkash and Erin Santini-Bell, Progressive damage detection of a vertical lift steel gussetless truss bridge by wavelet analysis, ASNT Research Symposium, Garden Grove, CA, April 1-4, 2019 (abstract is under review).
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Tidal Turbine Deployment System

The tidal turbine deployment system consists of vertical guide posts (VGPs) attached to the Portsmouth-facing side of Pier No.2 and a floating turbine deployment platform (TDP) on which a tidal turbine is installed and operated from.

The turbine was installed during June 6-8, 2018, and was operated for the first time in off-grid mode on the afternoon of June 8th. The UNH team spent the remainder of the summer operating the turbine in an off-grid mode while the team was present. The turbine was always removed from the water, when the team left the TDP. These tests were being performed to gain confidence in system operation to eventually operate the turbine in an unattended, on-grid mode. In August and September 2018, the adapter bracket was redesigned, fabricated and installed based on concerns related to excessive movement during turbine operation, see Figure 4 for original and revised adapter bracket. Bolts connecting the two piece generator housing were replaced with stronger bolts during the bracket replacement in October 2018.

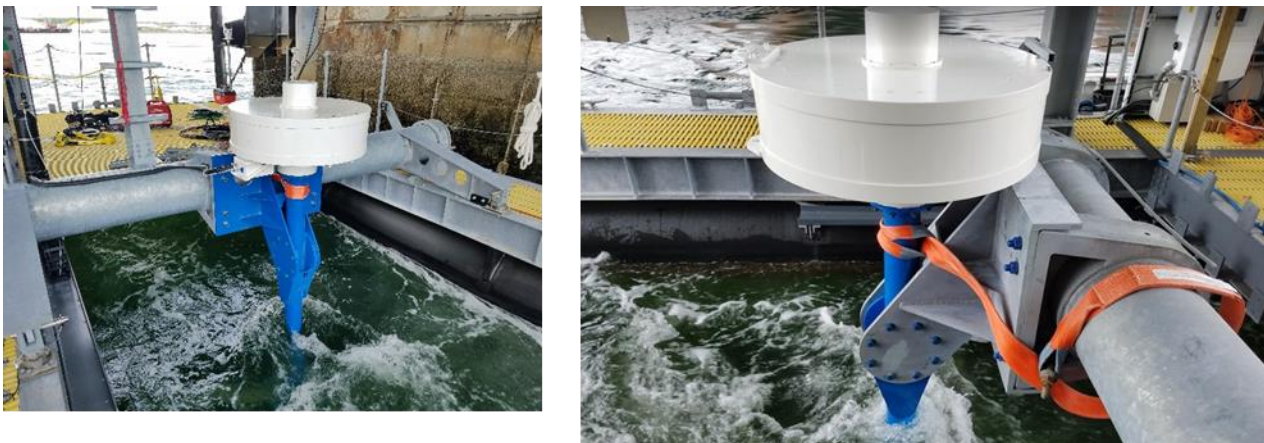


Figure 6: Turbine Operation at the Memorial Bridge (L) with original adapter bracket and (R) with the revised adapter bracket.

The grid connection application required by Eversource (“Interconnection Standards for Inverters Sized up to 100kVA: Simplified Process Interconnection Application and Service Agreement”) was completed by UNH with all technical

NHDOT SPR2 PROGRAM

RESEARCH PROGRESS REPORT

information, and sent to NH-DOT. The application was signed by NH-DOT and sent to UNH on 26 Sep 2018. The turbine system is operational in off-grid mode. Figure 7 show the power converted by the turbine as well as the coefficient of power for a spring ebb tide, collected on March 20 2019.

The turbine was first connected to the bridge grid to test grid-connected operation on 25 October 2018. Jeff Stevens, Master Electrician, of Northeast Integration (NEI), the electrical contractor for Memorial Bridge, inspected and measured outputs on all connections and then connected the inverter to the bridge grid. Several settings on the rectifier and inverter needed to be customized for the application, these adjustments were made over the next few test runs of the turbines on follow-on dates in November and December. Trouble-shooting of inverter errors led to the discovery of a faulty relay; the inverter was replaced with a new one supplied by the inverter manufacturer under warranty on March 14th and failed again. The selection of a new inverter is underway. This process has been initiated and is being managed by NEI.

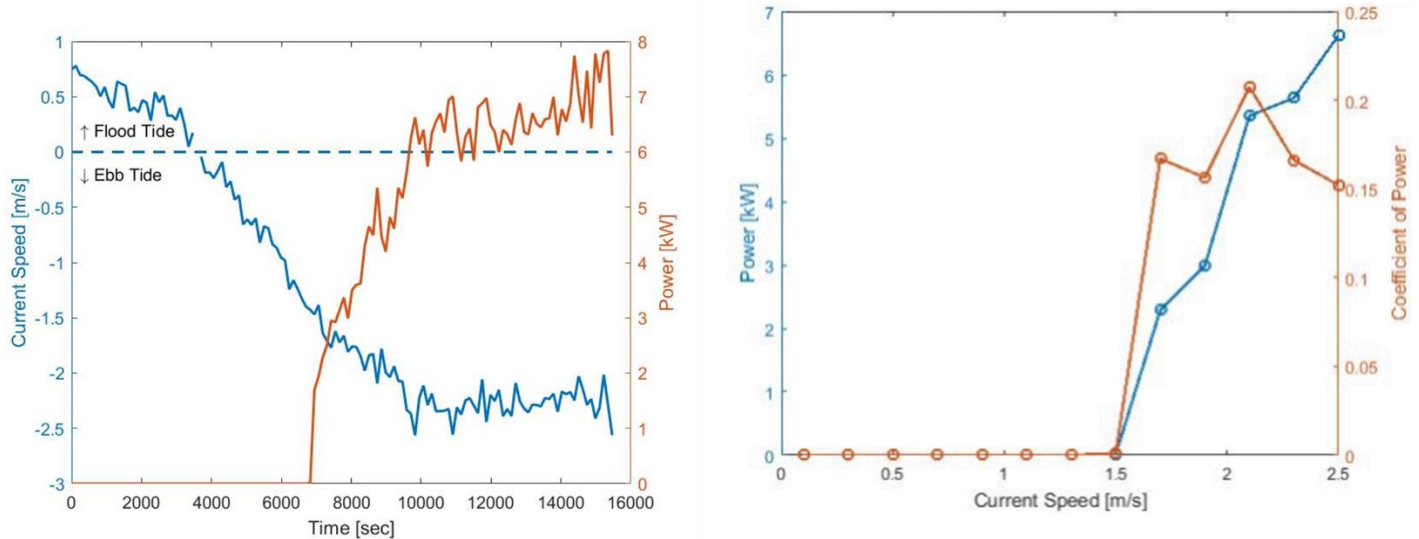


Figure 7: (A) Power and current data from an off-grid test on the ramp up of an ebb tide (2 min ensembles) And (B) Power curve from an off-grid test on the ramp up of an ebb tide (2 min, 0.2 m/s ensembles)

Items needed from NHDOT (i.e., Concurrence, Sub-contract, Assignments, Samples, Testing, etc):

UNH will need access protocols for the data closet at the bridge for maintenance of the data acquisition system.

UNH would like to repeat the load test again in March/April 2019 and will require the NHDOT approval and support for the load test.

NHDOT has provided approval for the grid connection of the tidal turbine. Martin Wosnik is work with Robert Spinney at the bridge for final connection.

Anticipated research through project completion:

As discussed at the March 29th 2019, TAG meeting, PI Bell will work with UNH to draft and MOU between UNH and NHDOT regarding the instrumentation and tidal turbine deployment system (TTDS) at the Memorial Bridge. This MOU will stipulate that the NHDOT will permit he instrumentation and TTDS to remain installed at the bridge for as long as research is active. Once the research efforts are completed, UNH will remove the instruments and TTDS, at their expense. PI will work on this MOU prior to the completion of this project.

Benchmark for Bridge Monitoring:

The integration of the structural health, mechanical operation and environmental instrumentation the sensors for remote access is complete. A trigger program has been established in March 2018 to trigger tentatively mechanical information. The proposed trigger protocol has been working efficiently so far. The event data files will be evaluated to refine the trigger limits.

NHDOT SPR2 PROGRAM

RESEARCH PROGRESS REPORT

The validation of the structural models of the Memorial Bridge in Lusas® as well as local model of selected gusset-less connections at the Memorial Bridge with respect to collected data in Fall 2017. Calibration of the structural models for condition and performance assessment with respect to design verification. These models have been preliminarily verified and are being used for condition assessment and operational decision making protocols. We have simulated damage in the structural models to show the expected deviation in structural measured response collected at the bridge if damage were to occur.

Tidal Turbine Deployment System

The deployment of the tidal turbine deployment platform (TDP) with estuarine sensors at the Memorial Bridge occurred in June 2017. The TDP was move to the UNH Pier for installation of the pitch mechanism in late 2017. The installation of the tidal turbine on the deployment platform was completed in June 2018, with power and communication connection installed in June 2018 by NEI.

The New Energy turbine was delivered in June 2018. It was mounted to TDP and then towed to the bridge. Strain data are being collected from the sensors on the vertical guide posts. Commissioning and initial testing was started in June 2018 and gird connection was planned for October 2018 due to a faulty inverter this connection was delayed and is planned for Spring 2019. The inverter was returned to the manufacturer for repair and is expected to be replaced in early February 2019. This inverter failed again and the selection of a new inverter in underway and will be installed at the site as soon as possible.

NHDOT SPR2 PROGRAM

RESEARCH PROGRESS REPORT

Circumstances affecting project: Describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope, and budget, along with recommended solutions to those problems.

As described in the “Progress this Quarter” section of this report, the schedule delay and increased cost related to the electrical conduit negatively impact this project.

Tasks (from Work Plan)	Planned % Complete	Actual % Complete
Living Bridge: Creating a Benchmark for Bridge Monitoring		
Project Coordination	100	100
Structural Model Creation	100	100
Design the instrumentation Plan	100	100
Sensor Deployment	100	100
Data Collection and Model Calibration	100	100
Trigger Protocol	100	100
Incorporation of collected data and model into NHDOT protocols	90	90
Final Report and Adoption Recommendation	0	0
Tidal Turbine Deployment Structure		
Deployment Structure Design	100	100
Project Permitting	100	100
Installation of Support Posts	100	100
Procurement of the Turbine deployment platform	100	100
Site Installation	100	100
Electrical Connection	100	90
Final Report and Poster	0	0